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RESEARCH MEMORANDUM

PANEL-FLUTTER INVESTIGATION AT SUPERSONIC SPEEDS OF A PRESSURIZED STRUCTURE FABRICATED OF 0.020-INCH-THICK LAMINATED GLASS-PLASTIC

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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PANEL-FLUTTER INVESTIGATION AT SUPERSONIC SPEEDS OF A PRESSURIZED STRUCTURE FABRICATED OF 0.020-INCH-THICK LAMINATED GLASS-PLASTIC

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SUMMARY

It has been proposed that the structural weight of supersonic missiles be reduced by the use of pressurized, thin-wall, glass-laminated shells. A model utilizing this type of structure was investigated in the Lewis 8- by 6-foot supersonic wind tunnel to determine the minimum internal pressure necessary to prevent panel flutter. The shell was fabricated from a 0.020-inch-thick glass-laminated skin in the form of a frustum of a cone and located behind a conical metal forebody.

No skin flutter or failure was observed at free-stream Mach numbers of 1.5 or 2.0 with either an empty shell at zero angle of attack or a shell half-filled with water at angles of attack of zero and 10°. The empty shell was investigated at positive pressure differentials (internal pressure greater than external pressure) from 6300 to 50 pounds per square foot at both Mach numbers. The shell half-filled with water was investigated at positive pressure differentials from 6300 to 700 pounds per square foot at a free-stream Mach number of 2.0 and from 6300 to 350 pounds per square foot at a free-stream Mach number of 1.5. Both shells were deformed, however, at a free-stream Mach number of 0.6 when a negative pressure differential was imposed. Raising the internal pressure returned the shell to its original shape.

INTRODUCTION

In order to reduce the structural weight of supersonic aircraft, it has been suggested that, if components such as fuel tanks were fabricated of thin, light, nonmetallic materials, the structural weight of missiles could be substantially reduced (ref. 1). Unfortunately, sheets of this type exposed to the air stream may be subject to panel flutter which in turn could destroy the integrity of the structure.

A theoretical approach to the panel-flutter problem (ref. 2) indicated that the tendency to flutter would be reduced if the panel were under tension. In reference 3 this was experimentally verified for flat metal panels; in addition, it was noted that a pressure differential across the skin had a damping effect on flutter. The purpose of the present investigation was to determine whether these same principles are applicable to a nonmetallic, laminated fiberglass skin formed into a closed structure.

In order to simulate the type of missile fuel cell which has its external skin exposed to the air stream, a 0.020-inch-thick test panel shaped as the frustum of a $3^{\circ}15'$ half-angle cone was placed behind a conical forebody. Pressure differentials from 50 to 6300 pounds per square foot were imposed on the test specimen at Mach numbers of 1.5 and 2.0 in the Lewis 8- by 6-foot supersonic wind tunnel at zero angle of attack. Similar conditions were again imposed at angles of attack of zero and 10° with the shell half-filled with water in simulation of a partially full fuel cell. The tendency of the skin to flutter and the local stresses imposed by the various conditions investigated are reported and discussed herein. Similar results are reported in reference 4. 3617

APPARATUS AND PROCEDURE

A photograph of the configuration investigated is presented in figure 1, and model details and dimensions are given in figure 2. The test specimen, which was sting-mounted in the tunnel test section, consisted of a metal conical nose section and a thin-wall simulated fuel cell. The skin was supported by two pressure bulkheads. The forward bulkhead was fixed to the sting, whereas the rear bulkhead was free to slide axially along the sting support. O-rings provided seals between the sting and the bulkheads. Under a 7200-pound-per-square-foot pressure differential the shell elongation was approximately 0.050 inch. This arrangement gave assurance that the fiberglass section was always under tension with a positive pressure differential across the shell.

The conical nose section was supported on the sting mount so that no bending moments were imposed on the test shell. In addition, the eight strain gages along the inner surface of the shell (fig. 2) were oriented to sense stress in an axial direction only. The signals generated by these gages were continuously recorded by a multichannel oscillograph. Two thermocouples were used to obtain the skin temperature.

The internal shell pressure was varied by admitting air into the shell through a pressure regulator indicated in figure 2. This pressure was sensed by four static orifices located in the forward bulkhead. Both internal pressure and external tunnel conditions were measured with mercury manometers and recorded photographically.

High-speed motion pictures of the model were taken through the schlieren window to obtain a record of any shell flutter or deformation. The stripes painted on the shell were intended to aid in detecting visually any shell deformation which might occur.

Specifications for the materials used in the fabrication of the laminated shell were furnished by the manufacturer and are as follows:

Glass cloth: Six plies of 112 - Volan A 0.003-inch thick

Aluminum foil: One lamina of 2S-O aluminum foil 0.002-inch thick (placed between the two innermost plies of glass cloth to prevent leakage)

Resin: Conolon 506

Adhesive: Metlbond X-181A (used to bond shell to metal bulkheads)

These materials had been cured for one hour at 350° F and a pressure of 15 pounds per square inch.

The experimentally obtained physical properties of the laminate and adhesive, also furnished by the manufacturer, are given below:

<u>Laminate</u>:

High temperature: Tensile strength, 32,400 pounds per square inch. (Tested at 500° F after aging for 5 hr at 500° F.)

Room temperature: Tensile strength, 36,900 pounds per square inch; Young's modulus, 1.87×10^6 pounds per square inch; Poisson's ratio, 0.27.

<u>Adhesive</u>:

High temperature: Shearing strength, 1267 pounds per square inch. (Tested at 500° F after aging for 5 hr at 500° F.)

Room temperature: Shearing strength, 1688 pounds per square inch.

The test was conducted in the Lewis 8- by 6-foot supersonic wind tunnel where the Reynolds number per foot was 5.2×10^6. Pressure differentials from 6300 pounds per square foot reduced successively to 50 pounds per square foot were imposed on the model at free-stream Mach numbers of 1.5 and 2.0. The empty shell was investigated at zero angle of attack, then half-filled with water to simulate a partially full fuel tank and investigated at angles of attack of zero and 10°. Some zero-angle-of-attack data were also taken at a free-stream Mach number of 0.6. The skin temperature was approximately 150° F during the entire investigation.

RESULTS AND DISCUSSION

After the model had been installed in the wind-tunnel test section, the natural frequency of the assembly was determined by sharply striking the shell normal to the axis and recording the strain-gage traces of the vibration decay. The natural frequency with no pressure differential across an empty shell was approximately 100 cycles per second. This value was reduced to about 50 cycles per second when the shell was half-filled with water. With a 1600-pound-per-square-foot differential across the shell, the driving impulse was immediately damped and no natural frequency obtained.

Empty Shell

Because the test shell is in the form of a conical element, the pressure distribution along the specimen length is not constant at free-stream Mach numbers greater than zero. The nature of these tests precluded any attempt to instrument the shell with static wall orifices to determine this distribution directly. Therefore, the method of reference 5, which is based upon second-order supersonic-flow theory, was employed to compute the static-pressure distribution on the shell at free-stream Mach numbers of 1.5 and 2.0 for zero angle of attack. By subtracting these external static pressures from the measured constant internal pressure applied within the shell, the axial distribution of the pressure differential across the shell is obtained. Figure 3 presents the distribution of pressure differential along the fiberglass section for minimum internal pressures of 800 pounds per square foot at a free-stream Mach number of 1.5 and 535 pounds per square foot at a free-stream Mach number of 2.0. No indication of flutter or shell failure was evident from either the high-speed motion pictures or the strain-gage records.

Tests at zero angle of attack and a free-stream Mach number of 0.6 were also conducted with the empty shell. Under these conditions a negative pressure differential (inner pressure lower than external pressure) could be imposed on the shell. At a local negative pressure differential of the order of 20 pounds per square foot, a slight deformation (flattening) of the shell was apparent. The single frame from the high-speed film which is reproduced in figure 4(a) shows the failure occurring. A photograph of the shell in its normal or uncollapsed state is also included (fig. 4(b)) for comparison. The latter photograph was obtained after the internal pressure was raised to a value sufficient to return the shell to its original shape. This value of the internal pressure was greater than 2006 pounds per square foot but less than 2860 pounds per square foot.

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Shell Containing Liquid

In order to simulate a partially full fuel cell, a second test specimen was half-filled with water and investigated at conditions similar to those of the investigation of the empty shell. Additional data were also obtained at a 10° angle of attack; however, since second-order theory has not been successful in predicting static-pressure distributions in the region of crossflow, the pressure differentials across the shell for the minimum internal pressure value imposed are presented for zero angle of attack only (fig. 5). At the two angles of attack, the minimum internal shell pressures imposed were approximately equal.

At neither free-stream Mach numbers of 1.5 nor 2.0 was any visual shell deformation or flutter apparent. The strain-gage instrumentation did, however, give some indication of erratic stress oscillations. Figure 6 presents a section of typical oscillograph traces and shows the random nature of the oscillations. Further indication of the erratic nature of these oscillations can be obtained from figure 7, which summarizes the dynamic stress data at a free-stream Mach number of 2.0. If a channel is not plotted, no measurable dynamic stress was recorded. It appears that the stress imposed on the shell varies with internal pressure, first increasing and then decreasing. The maximum values of dynamic stress observed, ±320 pounds per square inch, were still less than 1 percent of the steady-state ultimate tensile strength.

As in the case of the empty shell, the half-filled shell deformed when a negative pressure differential was applied at a free-stream Mach number of 0.6, but would return to its original shape when the internal pressure rose.

SUMMARY OF RESULTS

A glass-reinforced plastic shell having a 0.020-inch wall thickness and shaped as the frustum of a 3°15' half-angle cone was investigated in the 8- by 6-foot tunnel at Mach numbers of 1.5 and 2.0. No shell flutter or deformation was observed with a positive pressure differential as low as 50 pounds per square foot, the minimum investigated. The measured skin dynamic tensile stresses were negligible and were observed only during tests of the shell half-filled with water to simulate a partially full fuel cell. At a Mach number of 0.6 both shells were deformed by the application of a negative pressure differential, but returned to normal shape when the internal pressure was raised.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
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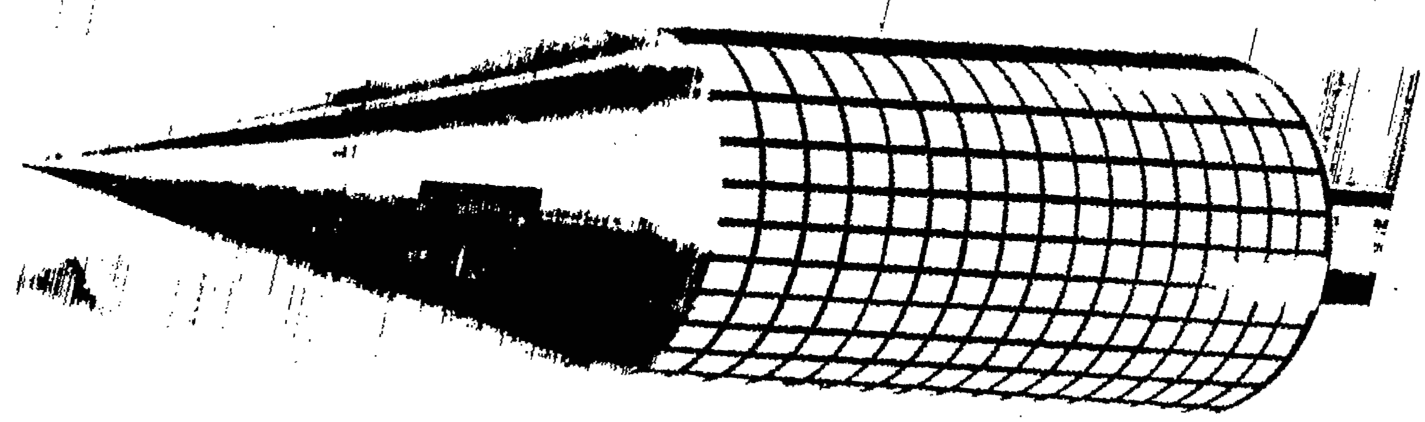


Figure 1. - Model used to study panel flutter. C-36974

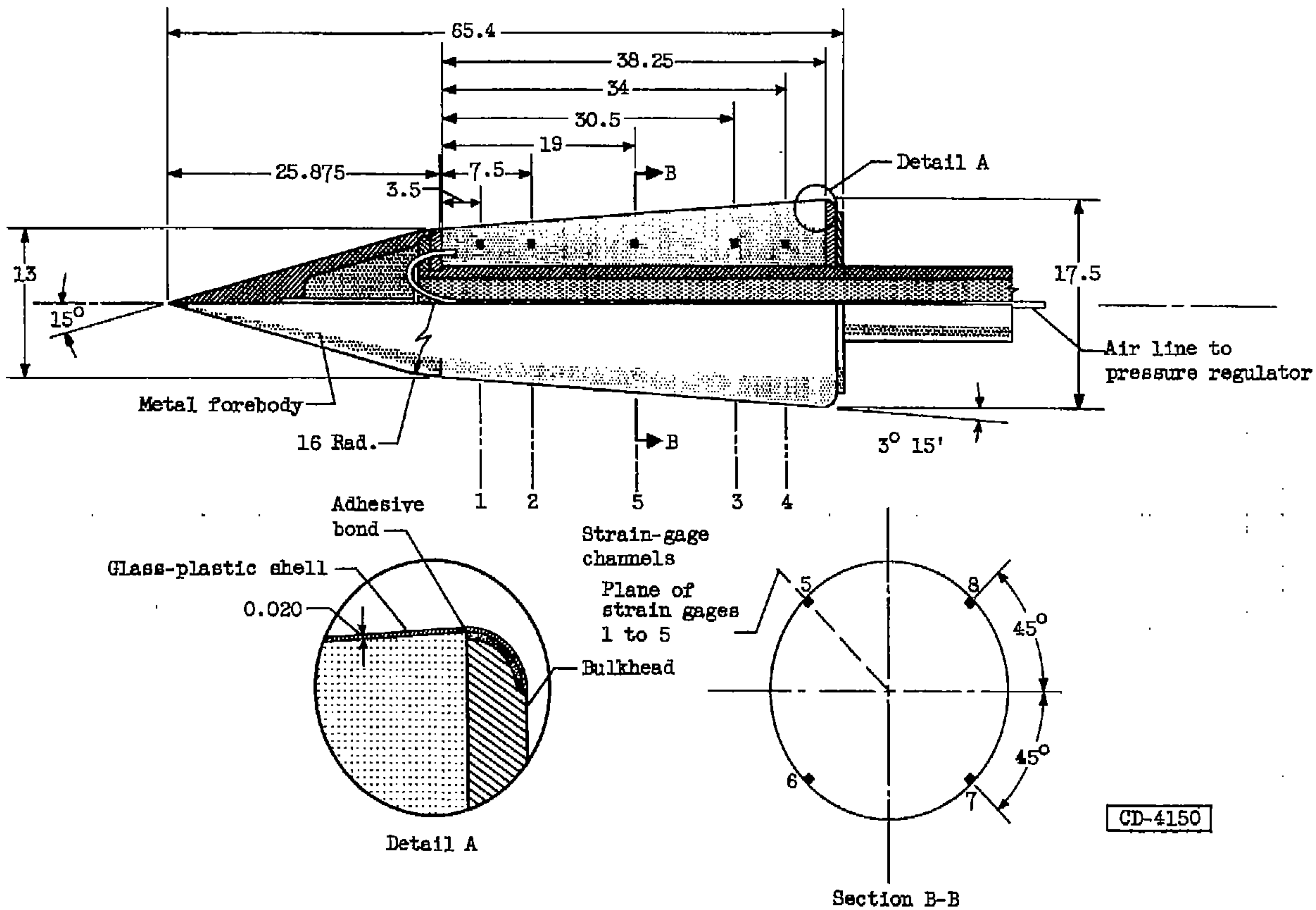
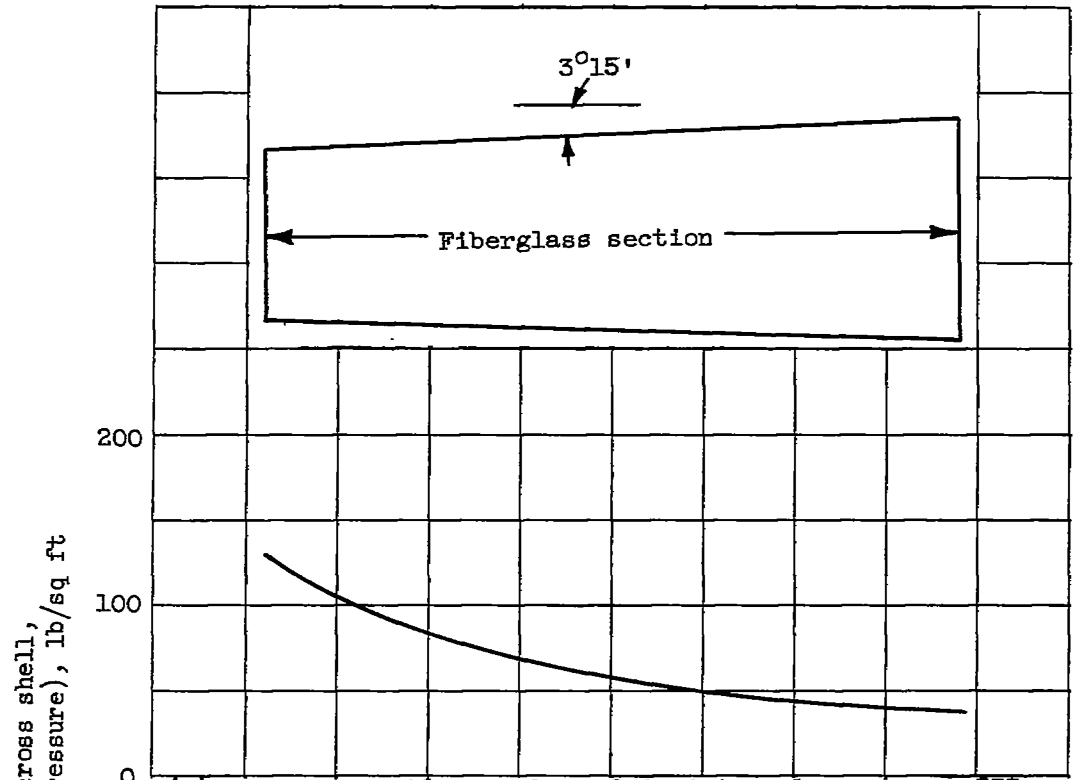
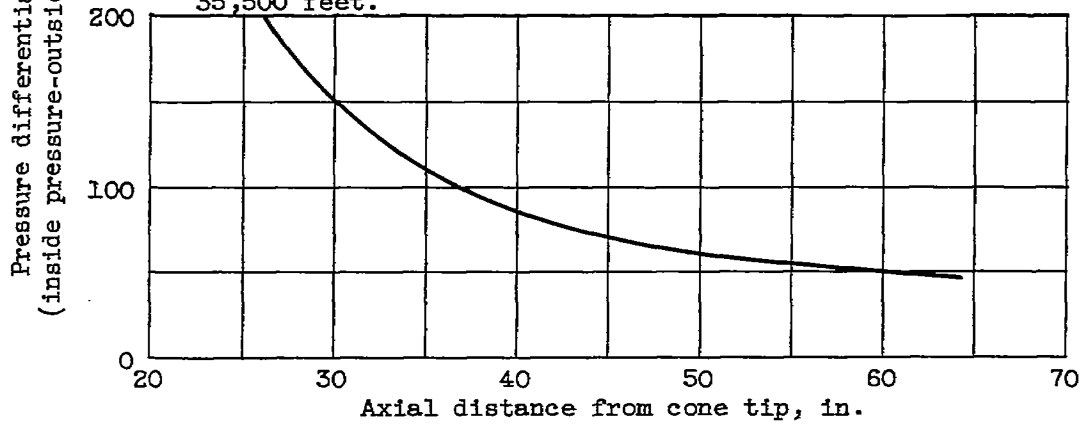


Figure 2. - Schematic drawing of model used for study of panel flutter. (Dimensions other than angles are in inches.)

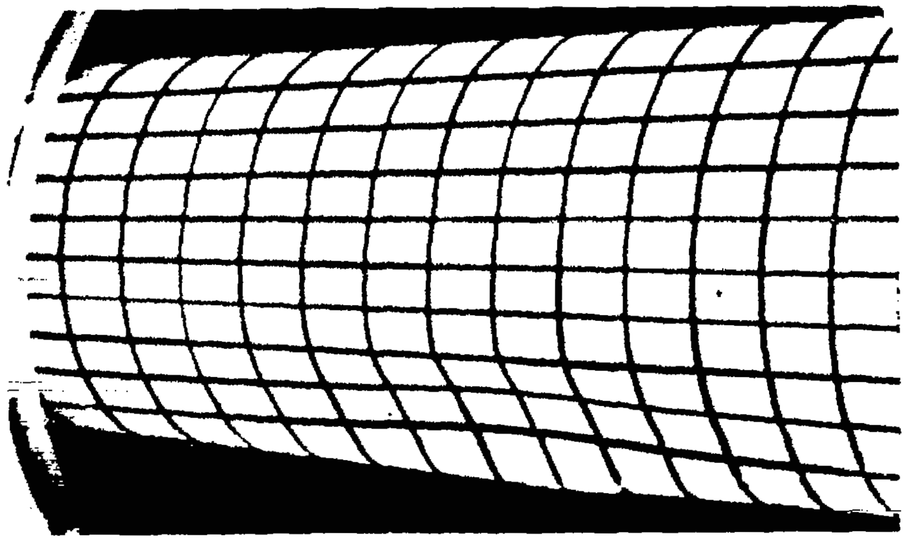


(a) Free-stream Mach number, 2.0; internal pressure, 535 pounds per square foot absolute; pressure altitude, 35,500 feet.

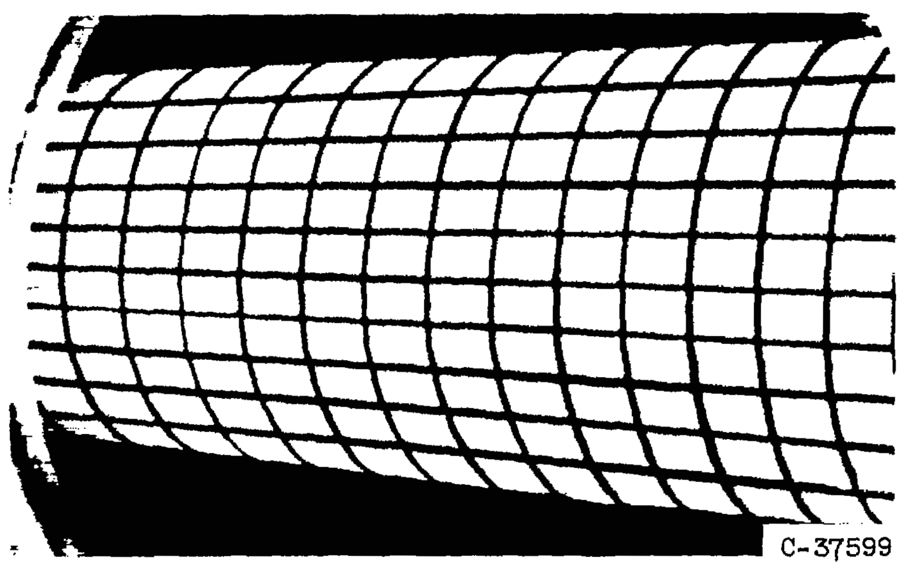


(b) Free-stream Mach number, 1.5; internal pressure, 800 pounds per square foot absolute; pressure altitude, 26,270 feet.

Figure 3. - Pressure-differential distribution across skin. Empty shell; minimum internal pressure; zero angle of attack.

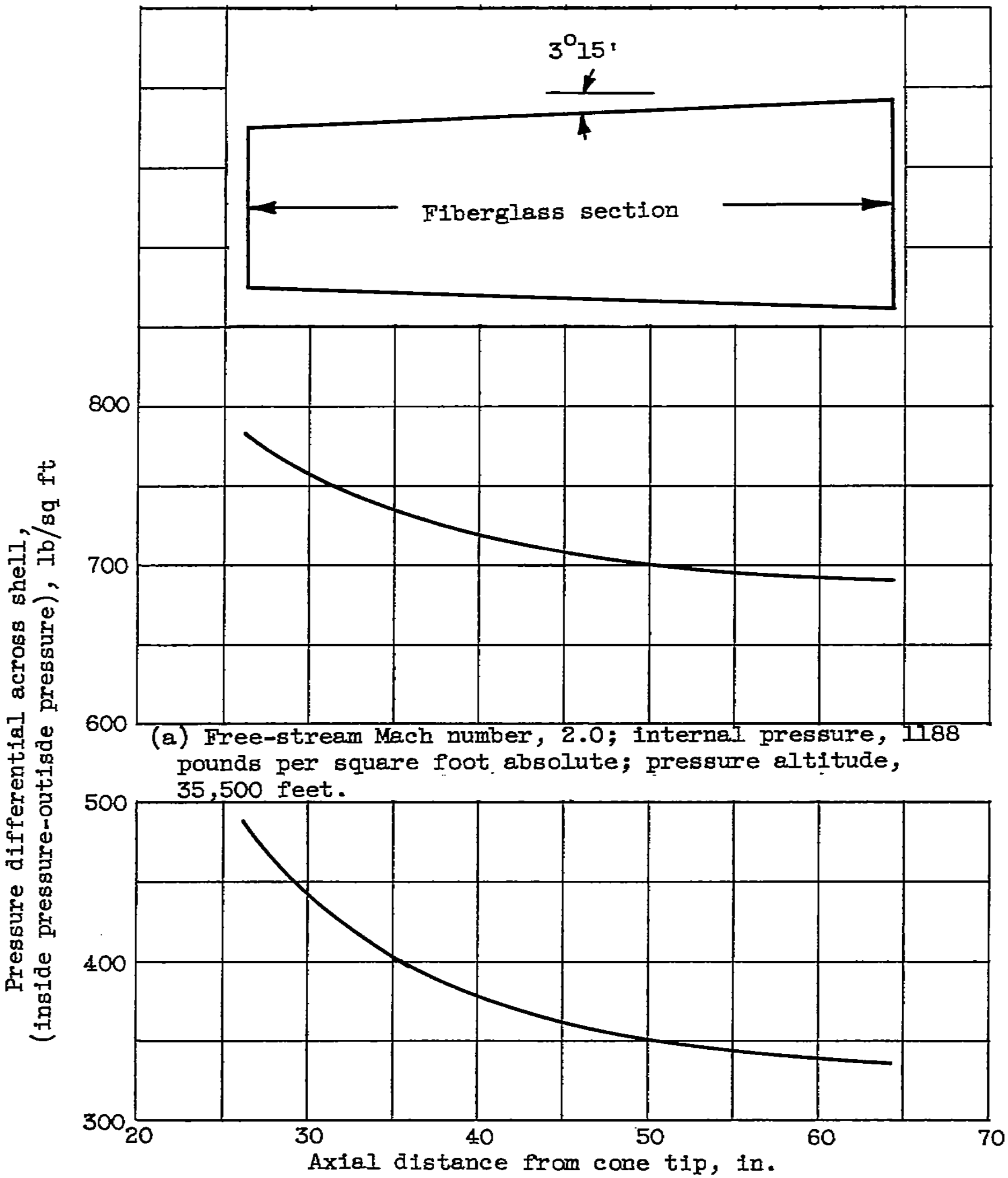


(a) Internal pressure, 2006 pounds per square foot absolute.



(b) Internal pressure between 2006 and 2860 pounds per square foot absolute.

Figure 4. - Photographs of collapsed shell before and after dent had been removed. Free-stream Mach number, 0.6.



(a) Free-stream Mach number, 2.0; internal pressure, 1188 pounds per square foot absolute; pressure altitude, 35,500 feet.

(b) Free-stream Mach number, 1.5; internal pressure, 1090 pounds per square foot absolute; pressure altitude, 26,270 feet.

Figure 5. - Pressure-differential distribution across skin. Shell half-filled with water; minimum internal pressure; zero angle of attack.

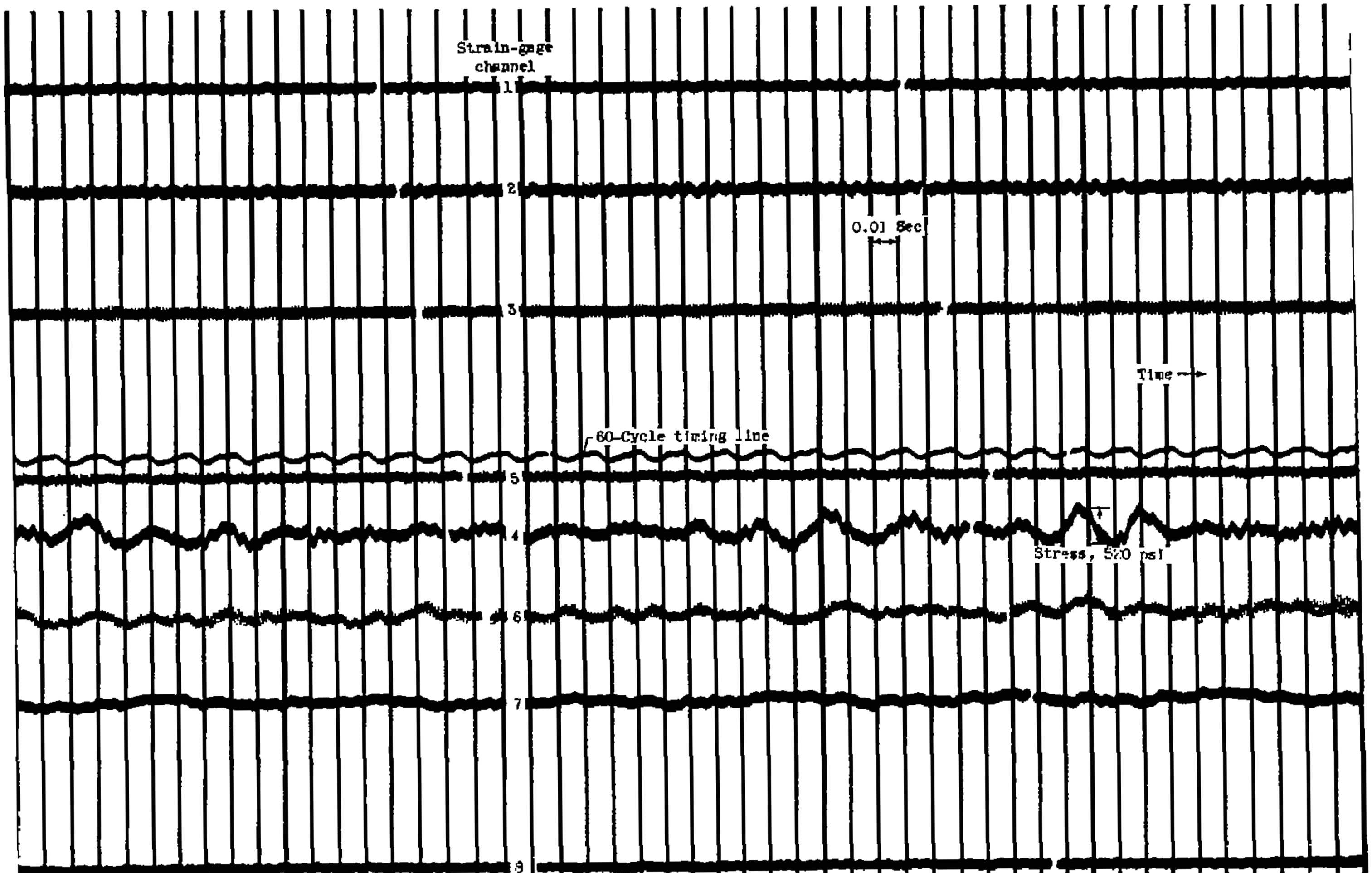


Figure 5. - Oscillograph trace of strain-gage signals. Shell half-filled with water; free-stream Mach number, 2.0; zero angle of attack; internal pressure, 1175 pounds per square foot absolute.

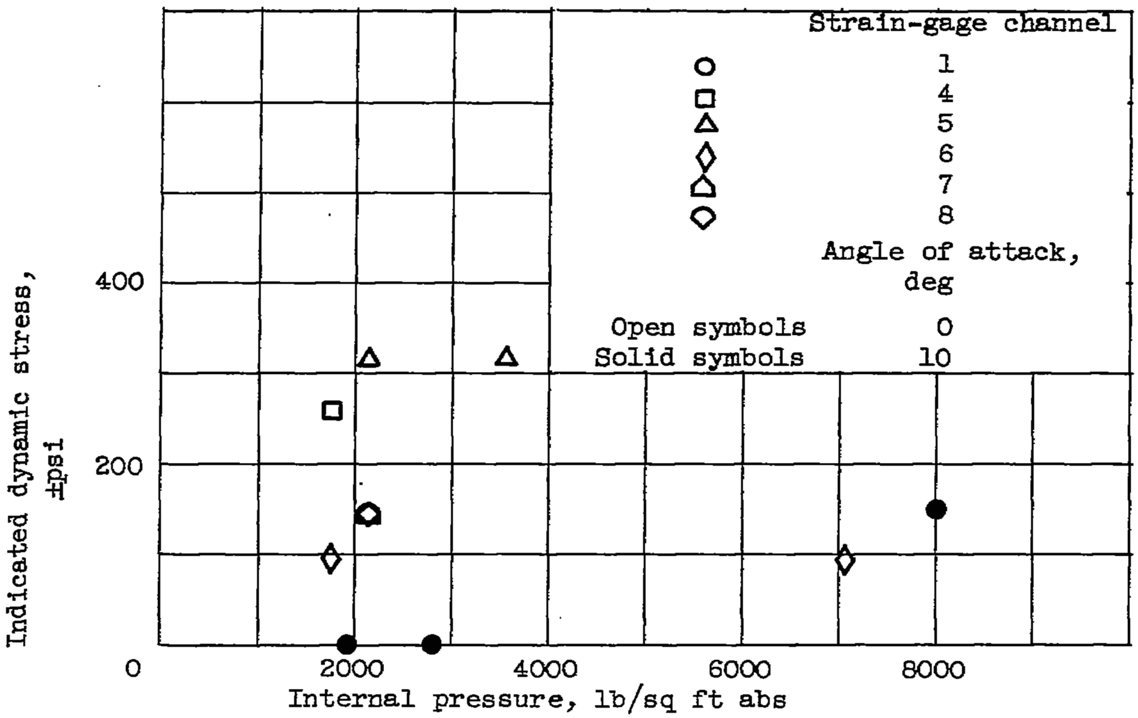


Figure 7. - Effect of internal pressure on shell dynamic stress. Free-stream Mach number, 2.0; pressure altitude, 35,500 feet.

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